

N90-29338

THE JAU-JPL ANTHROPOMORPHIC TELEROBOT

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ABSTRACT

This paper describes work in progress on the new anthropomorphic telerobot that is currently being built at JPL. The initial robot configuration consists of a seven d.o.f. arm and a sixteen d.o.f. hand, having three fingers and a thumb. The robot has active compliance, enabling subsequent dual arm manipulations. To control the rather complex configuration of this robot, an exoskeleton master arm harness and a glove controller have been built. The controller will be used for teleoperational tasks and as a research tool to efficiently teach the computer controller advanced manipulation techniques.

INTRODUCTION

Current-day robots lack the manipulation capabilities and sensing skills of the human arm-hand system. The development of this telerobot has as its goal to provide limited man-equivalent dual arm manipulation capabilities for remote material handling, servicing and other manipulative tasks that require mechanical dexterity together with real time evaluations of a variety of sensory information.

The initial thrust of this research is to demonstrate advanced manipulation skills at never before achieved levels through teleoperation. The teleoperation mode is used for unstructured tasks in changing environments where preprogramming is almost impossible. It will be very useful for the early space station construction, assembly and contingency tasks: The dual arm robot will serve as dexterous front end to an RMS arm that is located on the space station or at the space shuttle and will perform tasks that previously required EVA astronauts. The robot will be controlled from a remotely located IVA crew station such as the Shuttle's aft flight deck where the operator controls the robot through the exoskeleton controller in a natural and user friendly way by just simply performing the desired manipulations.

Once the initial space station construction phase is accomplished by the late nineties, the station's tasks may become more routine while robot controllers will have become more sophisticated so that limited autonomy of the robot system can be considered. The system can then be upgraded to a telerobot with shared man-machine control due to the active compliance and a variety of sensors that are already built into this robot. This paper, however, focuses primarily on the soon to be completed first master and slave units in teleoperational control mode.

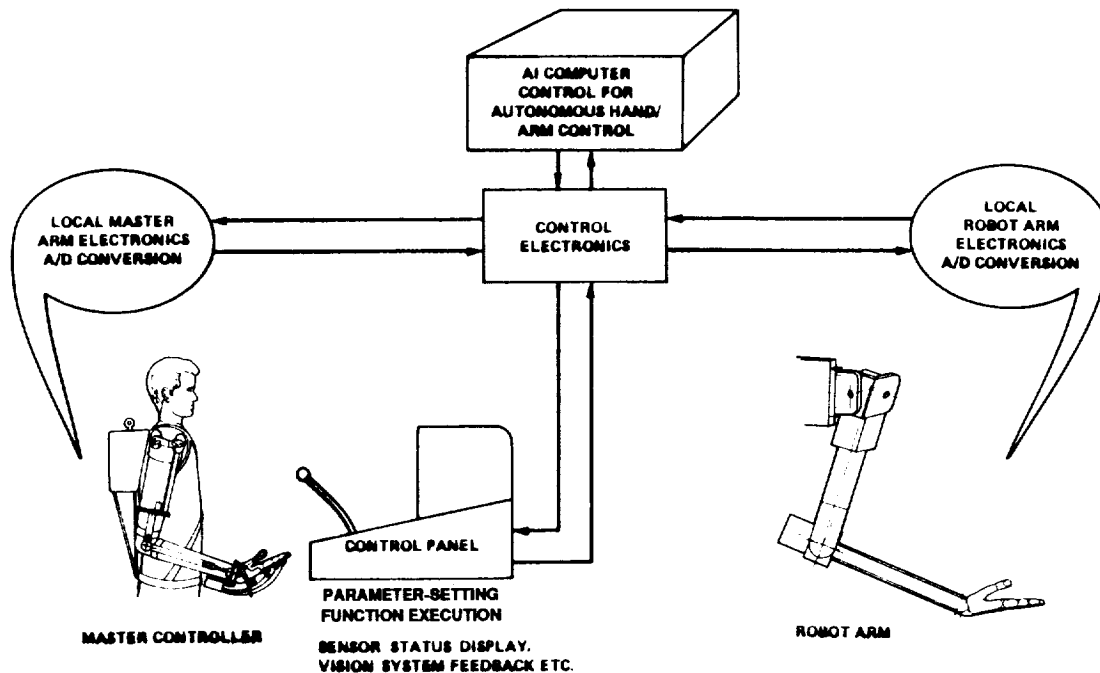


Fig.1 The Anthropomorphic Telerobot-Overall System

OVERALL SYSTEM

The initial system configuration is shown in Fig.1. It will consist of

- o An anthropomorphic arm-hand robot
- o An exoskeleton master arm harness and glove controller
- o The computer control electronics

The second phase will be the addition of symmetrical master and slave arms and automation aids. Subsequent developments will incorporate auxiliary equipment and tools, emphasizing tool manipulation skills. Local and global mono and stereo vision and other sensory systems will also be installed. Graphics and predictive displays will be used to aid time delayed operations for robot control from a ground station.

THE ROBOT ARM-HAND

The Robot arm-hand is sketched in Fig. 2 without its auxiliary devices such as cameras. The first arm is currently being constructed. It features the following items:

- o A mid-body section that has the two arm attachments on either side and an external attachment fixture at its back. The robot can be picked up by a carrying device such as the space shuttle's RMS arm.
- o Seven d.o.f. arms in the exact kinematic configuration as the master arm. An exact one-to-one kinematic correspondence between master and slave arm joints exists.

- o The hands have three fingers and a thumb, a palm, the three d.o.f. wrist and extend further through the forearm to the elbow. The finger drive mechanisms are located in the forearm and the wrist drives are located behind the elbow to counterbalance the arm.
- o Most joints feature limber joint active compliance control which imitates the human muscle capability to loosen or stiffen the joint. Active compliance is activated through electromechanical devices that are built into the joint mechanisms. Active compliance enables dual arm manipulations, soft grappling where the hand can conform to the object's shape, and it opens the way for sensor-driven control.
- o The mechanical hand also has the equivalent kinematic configuration as a glove controller so that the sensed human hand can provide direct teleoperational control, enabling the human hand to convey skilled hand manipulation techniques.
- o Position, force and compliance sensors are built into the prototype. Other sensors will be added at later phases.

THE EXOSKELETON ARM-GLOVE CONTROLLER

The device is shown in Fig. 2. It consists of seven d.o.f. arm harnesses and sixteen d.o.f. glove controllers. All joints have force input sensors, position sensors, and are electromechanically backdrivable. One master arm has been built thus far. The arms are suspended on an overhead translation stage to relieve the operator from the weight of the structure. The operator can work in a standing or seated position and is free to move or walk around as far as the weight suspension system allows him to do so.

Arm Harness

- o The base of the controller is a backframe that is being strapped to the operator's back. The backframe serves as reference position for subsequent arm joints. Any active or reaction forces are countered at the frame-human body interaction so that there are no external forces acting on the operator or on the controller. A recoil-free master controller is very important in the weightlessness of space.
- o Each side of the frame has an attachment for one of the symmetrical arms. Both arms work completely independently. Linear slides are built in between frame and arm support, allowing passive shoulder motions in all three principal directions. They provide freedom for movements for the operator, enabling him, for instance, to raise his shoulder. Further, they provide size adjustments to accommodate different-size operators.
- o The shoulder joint consists of three individually backdriven joints whose rotational axes intersect at the location which is concentric with the human shoulder ball joint.
- o A two d.o.f. counterbalancing mechanism, mounted on the arm support structure and acting on two of the shoulder joints, effectively counteracts the mass-moment of the arm assembly at any arm position. The operator is thus not burdened by having to support the mechanical arm at extended arm positions and will not fatigue while working with extended arms for lengthy time periods.

- o Two of the shoulder joint drives have mechanical overload release mechanisms built into their gear trains. This feature, which automatically separates the motor drive from the joint in overload situations, may prevent operator injuries and protects the mechanical arm in case of unforeseen circumstances.
- o Telescopic arm sections are provided for both the upper and lower arms, providing adjustment capabilities for different human arm lengths. The arm sections partially encase the operator's arm without significantly limiting his arm motion capabilities.
- o Special strap-on features are provided at two locations each on the upper and the lower arm to provide good motion compliance between the mechanical and the human arm.
- o The wrist also consists of three individually backdriven joints with their motor drives located near the wrist.

Glove Controller

The hand controller is a slip-into device that the operator can wear on his hand, thus the name glove controller. Three fingers and the thumb are instrumented, each finger unit has four d.o.f. The little finger is not being used at present since the slave hand will be four fingered as well.

Metal plates ride on the backside of each finger section. They are connected by linkages which have common pivot points above the finger joints. Each pivot point is the center for a pulley that rotates at equal angles as the finger joint. The pulleys are backdriven according to the slave's actual displacements to provide identical hand configurations for master and slave hands. The finger actuators are located in compact finger-drive packages at and above the elbow, also serving as counterweight for the forearm. The finger actuators are linked to the finger by means of flex cables.

CONTROL

Due to its exoskeleton, anthropomorphic shape, the operator is able to wear the dual arm control harness. He then just simply performs the desired operation manually while monitoring the events at TV screens or by looking through the control station's windows. Position and force feedback are reflected at each joint in the arm and hand, thus providing a sense of actually operating out there. The master and slave arms are linked by high-speed optical data transmission lines with communication rates of over 1000 Hz. Due to the matching kinematic configuration between master and slave arms, no time-delaying coordinate transformations have to be performed, which results in excellent feedback and response rates.

Compliance control is automatic: If the operator exerts a slight force to move a joint, the slave will respond and feeds the actual motion back to the master controller. If the slave joint is prevented from moving, the master controller will not respond either. Should the operator continue to exert a force to the controller, the controller still senses the operator's force input and produces a proportional force at the corresponding slave joints while at the same time stiffening its internal joint stiffness mechanisms. Position and force control are thus automatically regulated in a human like fashion without the operator having to switch from one mode to another.

SPACE OPERATIONS

The system has been designed with space applications in mind and could be readied for an early space experiment prior to the space station's construction. Fig. 2 shows the artist's concept of the space robot configuration. Employing this anthropomorphic system in space has considerable advantages. Some of them are listed below:

- o It is designed as dexterous front end to the standard RMS arm.
- o The System Hardware can be stowed in the shuttle's cargo bay. The slave will be picked up by the RMS arm. The master could be brought through the tunnel to the flight deck.
- o The dexterous hand can plug in tethering devices and electronic connectors, including its own electrical connections to the RMS arm.
- o The master requires no independent fixed space or attachments in the aft flight deck.
- o The operator wears the master on his back, eliminating disturbing recoiling effects.
- o The operator retains his mobility and by freezing the slave is free to manipulate the RMS controls.
- o One operator can perform a variety of EVA manipulation tasks that previously required two EVA astronauts and one RMS operator.
- o No EVA life support system is needed. No decompression time is required for the astronauts. No mandatory three-day waiting period for EVA operations is required at the beginning of a mission.
- o The system can quickly be deployed in contingency and emergency situations.

SUMMARY

The new anthropomorphic telerobot system was discussed. It will consist of dual robot arm-hands and an exoskeleton dual arm-glove controller. The hands have a thumb and three fingers. The robot arm-hand has active compliance which is essential for advanced dexterous robot manipulations. The control harness allows the operator to command the task by simply performing the desired manipulations. Advantages of this system for space applications were mentioned.

GLOSSARY

EVA: Extra Vehicular Activities: Space Walking Astronauts

IVA: Intra Vehicular Activities: Astronauts commanding the events from an environmentally controlled command post

RMS: Remote Manipulator System: The space shuttle's arm

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

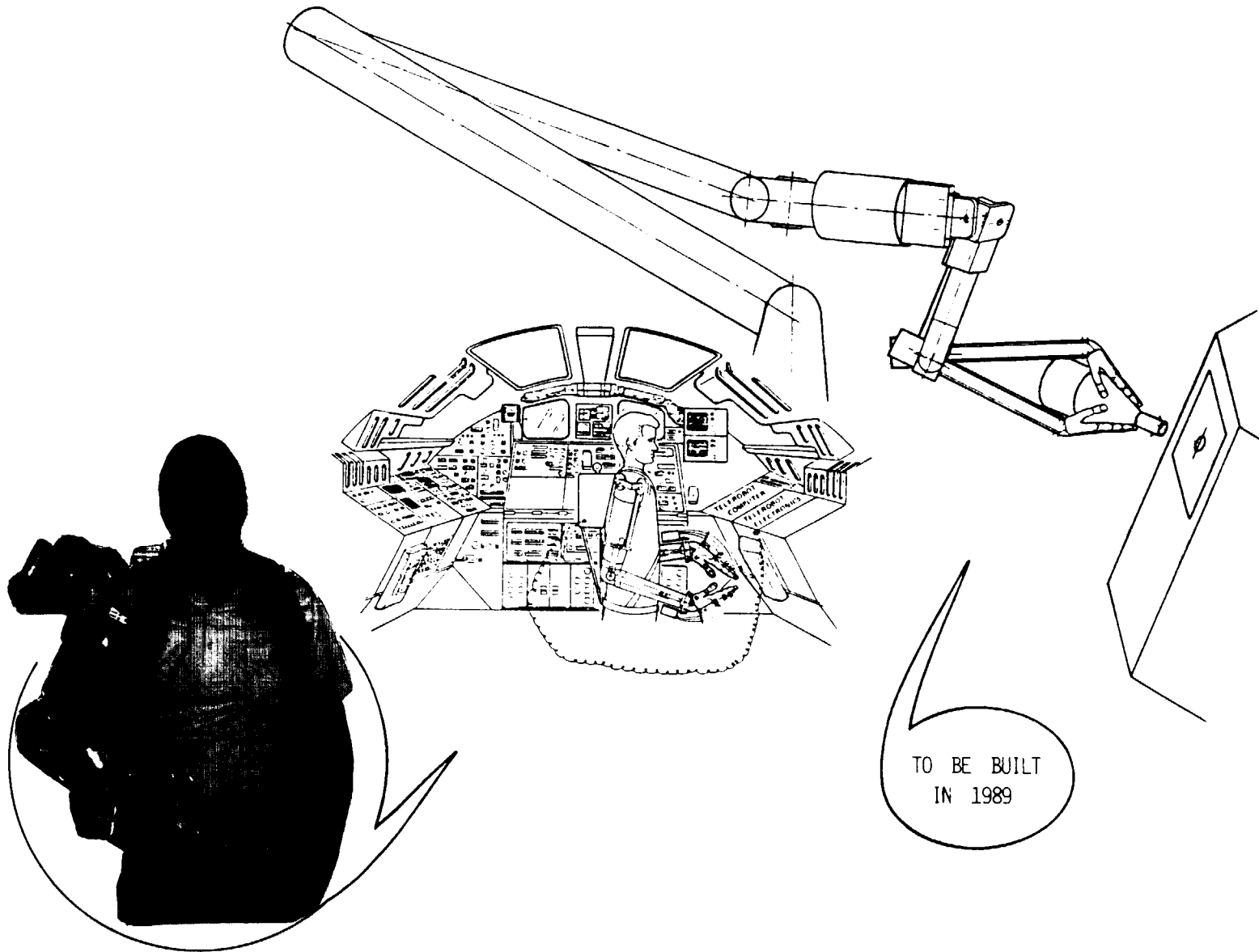


Fig. 2 Anthropomorphic Telerobot in Space Configuration